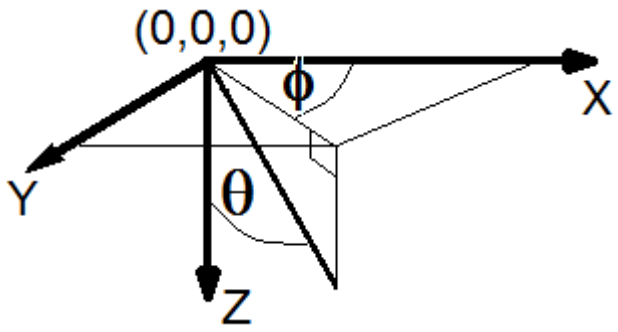
Light Sources for Monte Carlo Simulation

Contents

Definitions and parameters

Coordinate system and default values



1. The Cartesian coordinate system (right-hand rule) is used.
2. Center of each source is located at the origin (0, 0, 0). When a user defines the source location, corresponding source flag is set and translation operation is executed.
3. Direction of the source is defined relative to positive z-axis. Default directional unit vector is (0, 0, 1). User can change the direction of the source axis by specifying directional unit vector.
4. ϕ is azimuthal angle. Default azimuthal angle range is [0, 2π]
5. θ is polar angle. Default polar angle range to cover lower hemisphere ($z > 0$) is [0, $\pi/2$] and full sphere is [0, π].

Base Class

There is a base class for each source type that contains common attributes and operations (Eg. *PointSourceBase, LineSourceBase* etc).

Custom Sources

In custom sources, user has the freedom to set polar angle range and azimuthal angle range.

Source Profile

User can define two photon emission location distributions:

1. Flat: Flat distribution in space
   Example:

```
"SourceProfile": {
    "SourceProfileType": "Flat"
  },
```

2. Gaussian: Gaussian distribution in space. This profile can be used to implement Gaussian beams (For lasers: TEM_{00} only). 2D Gaussian distribution is given by following equation.

$$p(r) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{r^2}{2\sigma^2}\right)$$

where σ is standard deviation.

Box Mueller transform convert two independent uniform numbers ($\xi_1$and ξ_2) into two independent normally distributed random numbers (N_1 and N_2). Mean and standard deviation of the distribution are 0 and 1 respectively.

$$N_1 = \sqrt{-2\ln(\xi_1)}\cos(2\pi\xi_2)$$

$$N_2 = \sqrt{-2\ln(\xi_1)}\sin(2\pi\xi_2)\,.$$

After box Muller transform, normally distributed random numbers are multiplied by 0.8493218 * *beamFWHM.* The standard deviation of the beam is equal to the radius of the beam @ FWHM (*beamFWHM/2*). Following calculations show the Gaussian laser sources and annular sources.

When ξ_1 = 0, N1 and N2 $\rightarrow\infty$. But lasers have finite aperture. That means photons generated beyond the aperture opening (*outerRadius*) must be blocked. To satisfy this condition, we have to adjust the lower limit of the ξ_1. We implemented this without using rejection sampling. The maximum value of N1 and N2 must be *outerRadius* * $\cos(2\pi\xi_2)$ and *outerRadius* * $\sin(2\pi\xi_2)$. That means

$$outerRadius = 0.8493218 * beamFWHM\sqrt{-2\ln(\xi_{lowerlimit})}\,.$$

$$\xi_{lowerlimit} = \exp(-0.5k_1^2)$$

where $k_1 = \dfrac{outerRadius}{0.8493218 * beamFWHM}$

For annular sources, N1 and N2 must be greater than or equal to *innerRadius* of the circle. But when ξ_1 reaches 1, N1 becomes zero. To fulfill this condition we calculate the upper limit of ξ_1 similar to previous calculation.

$$innerRadius = 0.8493218 * beamFWHM\sqrt{-2\ln(\xi_{upperlimit})}$$

$$\xi_{upperlimit} = \exp(-0.5k_2^2)$$

where $k_2 = \dfrac{innerRadius}{0.8493218 * beamFWHM}$

when *innerRadius = 0*,

$$k_2 = 0 \text{ and } \xi_{upperlimit} = 1$$

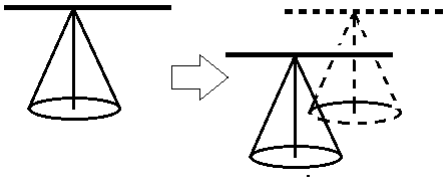
Example:

```
"SourceProfile": {
    "SourceProfileType": "Gaussian",
    "BeamDiaFWHM": 1.0
  },
```

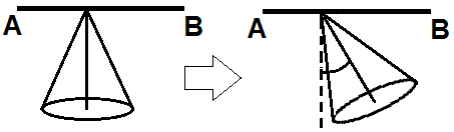
Translation, rotation and source flags

Source flags are used for three optional operations. When user assigns any value except default parameters for *translateFromOrigin, newDirectionOfPrincipalSourceAxis or , beamRotationFromInwardNormal*, source flags detect the change and carry out the required operation.

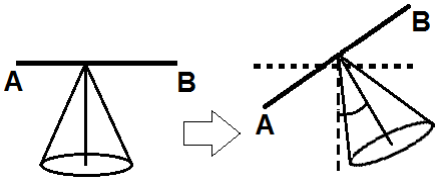
1. Translation from origin: The centers of all sources are defined at the origin. When new location is assigned, this flag is set to 1.



2. Beam rotation from inward normal: This operation only rotates the beam by given angle pair (polar and azimuthal). It does not modify the emitting location. When the angle pair is other than (0, 0), this flag is set to 1.



3. Rotation of principal source axis: This operation rotates the complete source towards the given direction. When the direction is other than (0,0,1), this flag is set to 1.



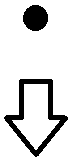
Description

1.1. Point and Line Sources

1.1.1. Point Source

Input parameters for *PointSourceBase* class are:

- *polarAngleEmissionRange*
- *azimuthalAngleEmissionRange*
- *direction*
- *pointLocation*
- *initialTissueRegionIndex*



Default position and geometry:

A point source is located at (0, 0, 0).

1.1.1.1. *DirectionalPointSource(direction, pointLocation, initialTissueRegionIndex)* : A user can define the emitting position (pointLocation) emitting direction (direction).

Example:

```
"SourceInput": {
  "SourceType": "DirectionalPoint",
  "PointLocation": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "Direction": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
 "InitialTissueRegionIndex": 0
},
```

1.1.1.2. *IsotropicPointSource(pointLocation, initialTissueRegionIndex)*: Isotropic emission of photons. By setting the location (pointLocation), user can place isotropic point source in any location

Example:

```
"SourceInput": {
  "SourceType": "DirectionalPoint",
  "PointLocation": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 5.0
  },
  "InitialTissueRegionIndex": 0
},
```

1.1.1.3. *Custom point source(polarAngleEmissionRange, azimuthalAngleEmissionRange, pointLocation, direction, initialTissueRegionIndex)*: User can set polar angle range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

Example:

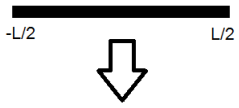
```
"SourceInput": {
  "SourceType": "CustomPoint",
  "PolarAngleEmissionRange": {
```

```
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
   },
   "AzimuthalAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
   },
"PointLocation": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
   },
   "Direction": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
   },
   "InitialTissueRegionIndex": 0
 },
```


1.1.2. Line Source

Input parameters for *LineSourceBase* class are:

- *lineLength*
- *sourceProfile*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *beamRotationFromInwardNormal*
- *initialTissueRegionIndex*



Default position and geometry:

A line source is defined such that the line is parallel to the x-axis. Center of the line is located at (0, 0, 0). *lineLength* (L) is the full length of the line source.

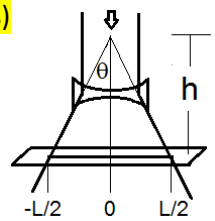
1.1.2.1. *DirectionalLineSource(thetaConvOrDiv , lineLength, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)*

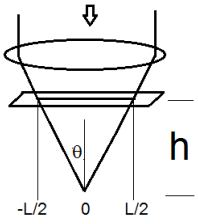
User can define converging, diverging or collimated line sources by setting *thetaConvOrDiv* (θ).

$\theta < 0$: Converging beam (negative angles)

$\theta > 0$: Diverging beam (positive angles)

$\theta = 0$: Collimated beam





If NA (numerical aperture) is known, calculate θ = arcsin(NA/n_{medium}) and provide correct sign to represent the convergence or divergence property. In directional sources, emitting direction depends on the emitting position. Following algorithm is used to calculate the direction.

i. Find the emitting location (l, 0, 0) in the line based on sourceProfile (Flat/Gaussian) type.

ii. For collimated sources, $\theta_{new} = \theta$.

iii. Otherwise, for diverging and diverging sources, calculate polar angle (θ_{new}) at emitting location using *UpdatePolarAngleForDirectionalSources(fulLength(L), curLength(l), thetaConvOrDiv(θ))* method.

$$\theta_{new} = 2\tan^{-1}(l) / L\tan\theta$$

where l is the length from the center to the emitting location

iv. Based on θ_{new} and emitting location, directional cosines are calculated by using *GetDirectionForGiven2DPositionAndGivenPolarAngle(polarAngle, position)* method.

New direction = $(sign(l)\times\sin\theta_{new},\ 0,\ \cos\theta_{new})$

Example:


```
"SourceInput": {
  "SourceType": "DirectionalLine",
  "ThetaConvOrDiv": 0.7071,
  "LineLength": 3.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
"NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
 },
```

1.1.2.2. *IsotropicLineSource(lineLength, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)*: Isotropic emission of photons from a line source.

Example:

```
  "SourceInput": {
    "SourceType": "IsotropicLine",
    "LineLength": 3.0,
    "SourceProfile": {
      "SourceProfileType": "Flat"
    },
   "NewDirectionOfPrincipalSourceAxis": {
      "Ux": 0.0,
      "Uy": 0.0,
      "Uz": 1.0
    },
    "TranslationFromOrigin": {
      "X": 0.0,
      "Y": 0.0,
      "Z": 0.0
    },
    "BeamRotationFromInwardNormal": {
      "Theta": 0.0,
      "Phi": 0.0
    },
    "InitialTissueRegionIndex": 0
  },
```

1.1.2.3. *CustomLineSource(lineLength, sourceProfile, polarAngleEmissionRange, azimuthalAngleEmissionRange newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)*: User can set polar angle range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

Example:

```
 "SourceInput": {
    "SourceType": "CustomLine",
    "LineLength": 3.0,
    "SourceProfile": {
      "SourceProfileType": "Flat"
    },
    "PolarAngleEmissionRange": {
      "Start": 0.0,
      "Stop": 0.0,
      "Count": 2
```

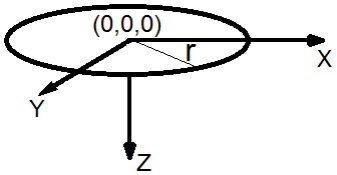
```
  },
  "AzimuthalAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
 "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
 },
```

1.2. Surface Emitting Flat Light Sources

1.2.1. Circular Sources

Input parameters for *CircularSourceBase* class are:

- *outerRadius*
- *innerRadius*
- *sourceProfile*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *beamRotationFromInwardNormal*
- *initialTissueRegionIndex*



Default position and geometry:

The 2D circular source lies on x-y plane. Center of the circle is located at (0, 0, 0). *outerRadius* is the radius of the circular source. User can define an annular source (*innerRadius* >0) or a full circular (*innerRadius* = 0) source. Emitting location on the circle (x, y) satisfies

$$x^2 + y^2 = r^2. \quad innerRadius \le r \le outerRadius$$

1.2.1.1. *DirectionalCircularSource(thetaConvOrDiv , outerRadius, innerRadius, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin,*

beamRotationFromInwardNormal, initialTissueRegionIndex) See 1.1.2.1 *DirectionalLineSource* for more details about directional sources.

Example: (Circular 45˚ (=0.7071rad) diverging beam)


```
"SourceInput": {
  "SourceType": "DirectionalCircular",
  "ThetaConvOrDiv": 0.7071,
  "OuterRadius": 3.0,
  "InnerRadius": 0.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "PolarAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
  "AzimuthalAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
 },
```


1.2.1.2. *CustomCircularSource(outerRadius, innerRadius, sourceProfile, polarAngleEmissionRange, azimuthalAngleEmissionRange, newDirectionOfPrincipalSourceAxis, translationFromOrigin , beamRotationFromInwardNormal, initialTissueRegionIndex)* User can set polar angle range and azimuthal angle range ().

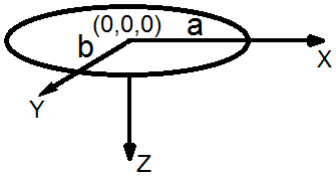
Example:

```
"SourceInput": {
  "SourceType": "CustomCircular",
  "OuterRadius": 3.0,
  "InnerRadius": 0.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "PolarAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
  "AzimuthalAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
 },
```

1.2.2. Elliptical Sources

Input parameters for *EllipticalSourceBase* class are:

- *aParameter*
- *bParameter*
- *sourceProfile*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *beamRotationFromInwardNormal*



- *initialTissueRegionIndex*

Default position and geometry:

The 2D elliptical source lies on x-y plane. Center of the ellipse is located at (0, 0, 0). The *aParameter* and *bParameter* are 'a' and 'b' parameter of the ellipse equation.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$$

1.2.2.1. *DirectionalEllipticalSource(thetaConvOrDiv , aParameter, bParameter, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)* See 1.1.2.1 *DirectionalLineSource* for more details about directional sources.

Example:

```
"SourceInput": {
  "SourceType": "DirectionalElliptical",
  "ThetaConvOrDiv": 0.7071,
  "AParameter": 3.0,
  "BParameter": 2.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
},
```

1.2.2.2. *CustomEllipticalSource(aParameter, bParameter, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)* User can set polar angle

range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

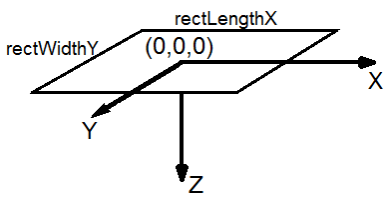
Example:


```
 "SourceInput": {
   "SourceType": "CustomElliptical",
   "AParameter": 3.0,
   "BParameter": 2.0,
   "SourceProfile": {
     "SourceProfileType": "Flat"
   },
    "PolarAngleEmissionRange": {
     "Start": 0.0,
     "Stop": 0.0,
     "Count": 2
   },
   "AzimuthalAngleEmissionRange": {
     "Start": 0.0,
     "Stop": 0.0,
     "Count": 2
   },
  "NewDirectionOfPrincipalSourceAxis": {
     "Ux": 0.0,
     "Uy": 0.0,
     "Uz": 1.0
   },
   "TranslationFromOrigin": {
     "X": 0.0,
     "Y": 0.0,
     "Z": 0.0
   },
   "BeamRotationFromInwardNormal": {
     "Theta": 0.0,
     "Phi": 0.0
   },
   "InitialTissueRegionIndex": 0
  },
```


1.2.3. Rectangular Sources

Input parameters for *RectangularSourceBase* class are:

- *rectLengthX*
- *rectWidthY*
- *sourceProfile*



- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *beamRotationFromInwardNormal*
- *initialTissueRegionIndex*

Default position and geometry:
The 2D rectangular source lies on x-y plane. Center of the rectangle is located at (0, 0, 0). Length (*rectLengthX)* and width (*rectWidthY)* parameters are parallel to x-axis and y-axis respectively.

1.2.3.1. *DirectionalRectangularSource(thetaConvOrDiv , rectLengthX, rectWidthY, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)* See *DirectionalLineSource* for more details about directional sources.

Example:

```
"SourceInput": {
  "SourceType": "DirectionalRectangular",
  "ThetaConvOrDiv": 0.7071,
  "RectLengthX": 3.0,
  "RectWidthY": 2.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
},
```

1.2.3.2. *CustomRectangularSource(rectLengthX, rectWidthY, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, beamRotationFromInwardNormal, initialTissueRegionIndex)* User can set polar angle

range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

Example:

```
 "SourceInput": {
   "SourceType": "CustomRectangular",
   "RectLengthX": 3.0,
   "RectWidthY": 2.0,
   "SourceProfile": {
     "SourceProfileType": "Flat"
   },
    "PolarAngleEmissionRange": {
     "Start": 0.0,
     "Stop": 0.0,
     "Count": 2
   },
   "AzimuthalAngleEmissionRange": {
     "Start": 0.0,
     "Stop": 0.0,
     "Count": 2
   },
  "NewDirectionOfPrincipalSourceAxis": {
     "Ux": 0.0,
     "Uy": 0.0,
     "Uz": 1.0
   },
   "TranslationFromOrigin": {
     "X": 0.0,
     "Y": 0.0,
     "Z": 0.0
   },
   "BeamRotationFromInwardNormal": {
     "Theta": 0.0,
     "Phi": 0.0
   },
   "InitialTissueRegionIndex": 0
 },
```

1.3. Surface Emitting Bulk Light Sources

1.3.1. Spherical Sources

Input parameters for *SurfaceEmittingSphericalSourceBase* class are:

- *radius*
- *polarAngleRangeToDefineSphericalSurface*

- *azimuthalAngleRangeToDefineSphericalSurface*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *initialTissueRegionIndex*

Default position and geometry:
Center of the sphere is located at (0, 0, 0). Surface of the sphere is defined by polar angle range (*polarAngleRangeToDefineSphericalSurface*) and azimuthal angle range (*azimuthalAngleRangeToDefineSphericalSurface*).

These examples show how we can define surface area of the sphere by using dual angle range variables.

1. Full sphere*:*
   polarAngleRangeToDefineSphericalSurface: [0, 2π]
   azimuthalAngleRangeToDefineSphericalSurface [0, π]
2. Lower hemisphere*: (z ≥ 0)*
   polarAngleRangeToDefineSphericalSurface: [0, 2π]
   azimuthalAngleRangeToDefineSphericalSurface [0, π/2]
3. Upper hemisphere*: (z ≤ 0)*
   polarAngleRangeToDefineSphericalSurface: [0, 2π]
   azimuthalAngleRangeToDefineSphericalSurface [π/2, π]
4. Lower left quarter sphere*: (x ≤ 0; z ≥ 0)*
   polarAngleRangeToDefineSphericalSurface: [π/2, 3π/2]
   azimuthalAngleRangeToDefineSphericalSurface [0, π/2]

1.3.1.1. *LambertianSurfaceEmittingSphericalSource(radius, translationFromOrigin, initialTissueRegionIndex)* Emission from each point is Lambertian.
Example:

```
"SourceInput": {
  "SourceType": "LambertianSurfaceEmittingSpherical",
  "Radius": 3.0,
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 3.0
  },
  "BeamRotationFromInwardNormal": {
    "Theta": 0.0,
    "Phi": 0.0
  },
  "InitialTissueRegionIndex": 0
},
```

1.3.1.2. *CustomSurfaceEmittingSphericalSource(radius, polarAngleRangeToDefineSphericalSurface, azimuthalAngleRangeToDefineSphericalSurface, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex)* User can define the emission surface by setting *polarAngleRangeToDefineSphericalSurface* and *azimuthalAngleRangeToDefineSphericalSurface*.

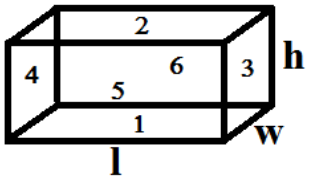
Example:

```
"SourceInput": {
  "SourceType": "CustomSurfaceEmittingSpherical",
  "Radius": 3.0,
   "PolarAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
  "AzimuthalAngleEmissionRange": {
    "Start": 0.0,
    "Stop": 0.0,
    "Count": 2
  },
 "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.0
  },
  "InitialTissueRegionIndex": 0
 },
```

1.3.2. Surface Emitting Cuboidal Sources

Input parameters for *SurfaceEmittingCuboidalSourceBase* class are:

- *cubeLengthX*
- *cubeWidthY*
- *cubeHeightZ*
- *sourceProfile*
- *polarAngleEmissionRange*
- *newDirectionOfPrincipalSourceAxis*



- *translationFromOrigin*
- *initialTissueRegionIndex*

Default position and geometry:
Center of the cuboid is located at (0, 0, 0). There are six rectangular emitting surfaces in the cuboid. *cubeLengthX, cubeWidthY, cubeHeightZ* that are aligned parallel to x, y and z-axis respectively are length, width and height of the cube. Total surface area of the cuboid is sampled to decide the emitting surface. All surfaces are emitting at equal probability. Emission profile can be either *Flat* or *Gaussian*. In current version, the user cannot enable/disable emitting surfaces. If we keep *NewDirectionOfPrincipalSourceAxis* as (0.0, 0.0, 1.0), to embed the source inside the tissue, change Z in "*TranslationFromOrigin*" to the value of *CubeHeight*/2.

1.3.2.1. *LambertianSurfaceEmittingCuboidalSource(cubeLengthX, cubeWidthY, cubeHeightZ, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex)* Emission from each point is Lambertian.

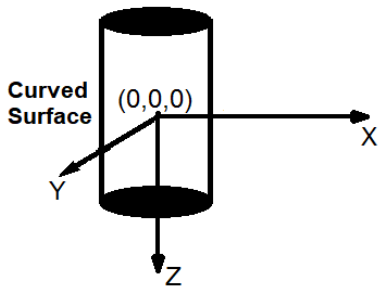
Example:

```
"SourceInput": {
  "SourceType": "LambertianSurfaceEmittingCuboidal",
  "CubeLengthX": 3.0,
  "CubeWidthY": 2.0,
  "CubeHeightZ": 1.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 0.5
  },
  "InitialTissueRegionIndex": 0
},
```

1.3.3. Tubular Sources

Input parameters for *SurfaceEmittingTubularSourceBase* class are:

- *tubeRadius*
- *tubeHeightZ*
- *newDirectionOfPrincipalSourceAxis*



- *translationFromOrigin*
- *initialTissueRegionIndex*

Default position and geometry:
Center of the tube is located at (0, 0, 0). Axis of the tube is parallel to the z-axis. *tubeHeightZ* and *tubeRadius are* height and the radius of the tubular source.

LambertianSurfaceEmittingTubularSource(tubeRadius, tubeHeightZ, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex) Emission from each location is Lambertian similar to light emission from a curved fiber surface. . If we keep *NewDirectionOfPrincipalSourceAxis* as (0.0, 0.0, 1.0), to embed the source inside the tissue, change Z in "*TranslationFromOrigin*" to the value of *TubeHeightZ*//2.

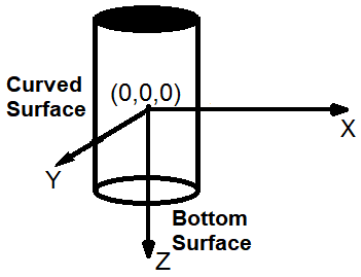
Example:

```
"SourceInput": {
  "SourceType": "LambertianSurfaceEmittingTubular",
  "TubeRadius": 3.0,
  "TubeHeightZ": 5.0,
 "NewDirectionOfPrincipalSourceAxis": {
   "Ux": 0.0,
   "Uy": 0.0,
   "Uz": 1.0
  },
  "TranslationFromOrigin": {
   "X": 0.0,
   "Y": 0.0,
   "Z": 2.5
  },
  "InitialTissueRegionIndex": 0
 },
```

1.3.4. Cylindrical fiber Sources

Input parameters for *SurfaceEmittingCylindricalFiberSourceBase* class are:

- *fiberRadius*
- *fiberHeightZ*
- *curvedSurfaceEfficiency*
- *bottomSurfaceEfficiency*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *initialTissueRegionIndex*



Default position and geometry:
Center of the cylindrical fiber is located at (0, 0, 0). Axis of the cylinder is parallel to the z-axis. *fiberHeightZ* and *fiberRadius are* height and the radius of the cylindrical fiber source respectively.

This fiber source has two emitting surfaces: curved surface (equivalent to tubular source) and bottom surface (equivalent to circular source). No emission from the top.

LambertianSurfaceEmittingCylindricalFiberSource(fiberRadius, fiberHeightZ, curvedSurfaceEfficiency, bottomSurfaceEfficiency, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex) Emission from each location is Lambertian. Total surface area and emitting efficiencies (*curvedSurfaceEfficiency, bottomSurfaceEfficiency*) are combined and sampled to select the emitting surface. . If we keep *NewDirectionOfPrincipalSourceAxis* as (0.0, 0.0, 1.0), to embed the source inside the tissue, change Z in "*TranslationFromOrigin*" to the value of *FiberHeightZ*/2.

Example:

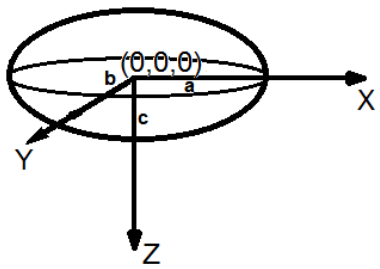
```
"SourceInput": {
  "SourceType": "LambertianSurfaceEmittingCylindricalFiber",
    "FiberRadius": 3.0,
    "FiberHeightZ": 5.0,
    "CurvedSurfaceEfficiency": 0.5,
    "BottomSurfaceEfficiency": 0.2,
    "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 2.5
  },
  "InitialTissueRegionIndex": 0
},
```

1.4. Volumetric Light Sources

1.4.1. Ellipsoidal Sources

Input parameters for *VolumetricEllipsoidalSourceBase* class are:

- *aParameter*
- *bParameter*
- *cParameter*
- *sourceProfile*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *initialTissueRegionIndex*



Default position and geometry:

Center of the ellipsoid is located at (0, 0, 0). *aParameter*, *bParameter, cParameter* are 'a', 'b' and 'c' parameters of ellipsoid equation.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$$

IsotropicVolumetricEllipsoidalSource(aParameter, bParameter, cParameter, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex) Isotropic emission of photons from a volumetric ellipsoid. If we keep *NewDirectionOfPrincipalSourceAxis* as (0.0, 0.0, 1.0), to embed the source inside the tissue, change Z in "*TranslationFromOrigin*" to the value of *CParameter.*

1.4.1.1. Example:


```
"SourceInput": {
  "SourceType": "IsotropicVolumetricEllipsoidal",
  "AParameter": 3.0,
  "BParameter": 2.0,
  "CParameter": 2.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 2.0
  },
  "InitialTissueRegionIndex": 0
},
```


1.4.1.2. *CustomVolumetricEllipsoidalSource(aParameter, bParameter, cParameter, sourceProfile, polarEmissionRange, azimuthal EmissionRange, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex)* User can define polar angle range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

Example:


```
"SourceInput": {
  "SourceType": "CustomVolumetricEllipsoidal",
  "AParameter": 3.0,
  "BParameter": 2.0,
```

```
    "CParameter": 2.0,
    "SourceProfile": {
      "SourceProfileType": "Flat"
    },
     "PolarAngleEmissionRange": {
      "Start": 0.0,
      "Stop": 0.0,
      "Count": 2
    },
    "AzimuthalAngleEmissionRange": {
      "Start": 0.0,
      "Stop": 0.0,
      "Count": 2
    },
    "NewDirectionOfPrincipalSourceAxis": {
      "Ux": 0.0,
      "Uy": 0.0,
      "Uz": 1.0
    },
    "TranslationFromOrigin": {
      "X": 0.0,
      "Y": 0.0,
      "Z": 2.0
    },
    "InitialTissueRegionIndex": 0
  },
```


1.4.2. Volumetric Cuboidal Sources (To represent voxel emission)

Input parameters for *VolumetricCuboidalSourceBase* class are:

- *cubeLengthX*
- *cubeWidthY*
- *cubeHeightZ*
- *SourceProfile*
- *newDirectionOfPrincipalSourceAxis*
- *translationFromOrigin*
- *initialTissueRegionIndex*

Default position and geometry:

Center of the cuboidal is located at (0, 0, 0). *cubeLengthX, cubeWidthY, cubeHeightZ* aligned parallel to x, y and z-axis are length, width and height of the cube respectively. If we keep

NewDirectionOfPrincipalSourceAxis as (0.0, 0.0, 1.0), to embed the source inside the tissue, change Z in "*TranslationFromOrigin*" to the value of *CubeHeight*/2.

1.4.2.1. *IsotropicVolumetricCuboidaSource(cubeLengthX, cubeWidthY, cubeHeightZ, sourceProfile, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex)* Isotropic emission of photons from a volumetric cuboidal.

Example:

```
"SourceInput": {
  "SourceType": "IsotropicVolumetricCuboidal",
  "CubeLengthX": 3.0,
  "CubeWidthY": 2.0,
  "CubeHeightZ": 2.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
  "NewDirectionOfPrincipalSourceAxis": {
    "Ux": 0.0,
    "Uy": 0.0,
    "Uz": 1.0
  },
  "TranslationFromOrigin": {
    "X": 0.0,
    "Y": 0.0,
    "Z": 1.0
  },
  "InitialTissueRegionIndex": 0
},
```

1.4.2.2. *CustomVolumetricCuboidalSource(cubeLengthX, cubeWidthY, cubeHeightZ, sourceProfile, polarEmissionRange, azimuthal EmissionRange, newDirectionOfPrincipalSourceAxis, translationFromOrigin, initialTissueRegionIndex)* User can define polar angle range and azimuthal angle range (*polarAngleEmissionRange* and *azimuthalAngleEmissionRange*).

Example:

```
"SourceInput": {
  "SourceType": "CustomVolumetricCuboidal",
  "cubeLengthX": 3.0,
  "cubeWidthY": 2.0,
  "cubeHeightZ": 2.0,
  "SourceProfile": {
    "SourceProfileType": "Flat"
  },
   "PolarAngleEmissionRange": {
    "Start": 0.0,
```

```
      "Stop": 0.0,
      "Count": 2
    },
    "AzimuthalAngleEmissionRange": {
      "Start": 0.0,
      "Stop": 0.0,
      "Count": 2
    },
    "NewDirectionOfPrincipalSourceAxis": {
      "Ux": 0.0,
      "Uy": 0.0,
      "Uz": 1.0
    },
    "TranslationFromOrigin": {
      "X": 0.0,
      "Y": 0.0,
      "Z": 1.0
    },
    "InitialTissueRegionIndex": 0
  },
```